Germplasm Diversity among Four Sugarcane Species for Sugar Composition

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ABSTRACT

The characterization of the World Collection of Sugarcane is needed for effective preservation and use of genetic resources. The objective of this study was to evaluate sugarcane germplasm from field plots by means of an analysis of sugar composition of four *Saccharum* species (32 *S. officinarum* L., 30 *S. barberi* Jesw., 27 *S. robustum* Brandes and Jeswiet ex Grassl, and 28 *S. sinense* Roxb.) plus four commercial cultivars. Stalks were cut from all clones of 1-yr-old plant cane and 11 clones from the first ratoon crop were crushed for juice analysis by conventional (Brix-pol) and high performance liquid chromatography (HPLC) methods. Most juice quality measurements showed a significant interaction between clones and crop cycles. The frequency distribution of sucrose content of the plant cane for *S. officinarum*, *S. barberi*, and *S. robustum* showed a marked skewness toward high sucrose content. The four species, however, showed different trends based on sugar content: *S. officinarum* clones were distributed in the plot of low glucose and fructose contents with sucrose content extending from low to high; *S. sinense* clones were distributed in the plot from low sucrose and low glucose–fructose to high sucrose and high glucose–fructose; and *S. barberi* and *S. robustum* clones were distributed in the plot between the former two species. Cluster analysis also indicated the heterogeneity within and among these four species. Information on sugar composition should assist curators in separating clones in their collection and breeders in selecting superior clones for use in their breeding programs.

The World Collection of Sugarcane and related grasses is currently vegetatively maintained at both USDA-ARS Clonal Germplasm Repository, Miami, FL, and the Sugarcane Breeding Institute, Coimbatore, India. The Collection at Miami contains 303 accessions of *S. officinarum* L., 41 *S. sinense* Roxb., 55 *S. barberi* Jesw., and 84 *S. robustum* Brandes and Jeswiet ex Grassl (Schnell and Lewis, 1996). A limited number of accessions has been used in the production of modern sugarcane cultivars (Berding and Roach, 1987). One reason for this is the lack of characterization of clones in the collection. Sugar content is one of the most important traits in a commercial sugarcane breeding program. The information on sugar composition can assist curators in differentiating clones in the germplasm collection and help sugarcane breeders enhance the effective use of germplasm. The introduction of new germplasm could enhance the successful development of improved sugarcane cultivars. Classification of the species of *Saccharum* has been carried out by various sugarcane botanists (Barber, 1918; Jeswiet, 1925; Mukherjee, 1954; Artschwager, 1954; Artschwager and Brandes, 1958). On the basis of morphological characteristics of the leaf, stalk, and inflorescence, the genus was divided into six species (*S. officinarum*, *S. barberi*, *S. sinense*, *S. spontaneum* L., *S. robustum*, and *S. edule* Hassk.) (Artschwager and Brandes, 1958; Daniels and Roach, 1987), which are commonly used in sugarcane breeding programs. Artschwager and Brandes (1958) pointed out that clear-cut separations of *S. officinarum*, *S. sinense*, and *S. barberi* are more difficult than those of the wild species, *S. spontaneum* and *S. robustum*. *Saccharum barberi* and *S. sinense* have been cultivated for centuries in northern India and China, respectively (Arstschwager, 1954). Barber (1918) classified northern Indian canes into five major groups: Mungo, Nargori, Saretha, Sunnabile, and Pansahi. These major groups excluding Pansahi were named *S. barberi* by Jeswiet (1925). The Pansahi clones, which are also found in Indochina, south China, and Taiwan, were included in Jeswiet's *S. sinense* group (Jeswiet, 1925). Northern Indian canes are believed to have been derived from *S. spontaneum* through mutation and selection (Barber, 1918; Jeswiet, 1925). Grassl (1977) proposed, however, that *S. sinense* clones were the products of *S. officinarum* × *Miscanthus saccariflorus* (Maxim.) Benth. introgression.

Artschwager and Brandes (1958) pointed out that the carbohydrates synthesized and stored in sugarcane, particularly sucrose and starch, corroborate, to a surprising degree, the boundaries of species and racial groups on the basis of taxonomic grouping. Jeswiet (1920) used sugar concentration to separate groups of *S. officinarum*. Dutt and Narasimhan (1951) tested starch accumulation in the stems of 215 wild species and cultivars and found that *S. robustum* and *S. officinarum* had, at most, a trace of starch, whereas *S. spontaneum*, *S. sinense*, and *S. barberi* accumulated much starch. HPLC has been used for quantifying plant chemical constituents (Bianchini and Gaydou, 1980; Stewart et al., 1979; Stewart et al., 1980). This technique also has been used for distinguishing among *S. spontaneum* clones on the basis of their sugar profiles (Tai et al., 1998; Tai and Miller, 2001).

Sugar composition would be useful for grouping clones in the germplasm collection. Those clones with high sucrose content may carry useful sugar genes for improving the current sugarcane cultivars. The objective of this study was to characterize sugarcane germplasm by means of an analysis of sugar composition of four *Saccharum* species, *S. officinarum*, *S. barberi*, *S. robustum*, and *S. sinense*.

MATERIALS AND METHODS

Accessions of four *Saccharum* species (32 from *S. officinarum*, 30 from *S. barberi*, 27 from *S. robustum*, and 28 from *S. sinense*) from the World Collection of Sugarcane and Related Grasses in Miami, FL (Schnell and Lewis, 1996) and four commercial cultivars (CP 70-1133, CP 72-1210, CP 72-2086, and POJ 2725) were established at USDA-ARS Sugarcane Field Station, Canal Point, FL, on Torry muck (Euic, hyper-

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thermic typic Medisaprist) in March 1999. These clones represented about 11% of *S. officinarum*, 55% of *S. barberi*, 50% of *S. robustum*, and 68% of *S. sinense* clones that are being maintained at Miami. One stalk sample from each of two replications was collected in March 2000. Juice samples of 11 clones (three commercial checks and two clones from each species) also were collected from the second-year (first ratoon) crop in February 2001 to measure juice quality. Each cane stalk sample consisted of 3 to 8 stalks depending on the stalk diameter and was divided equally into three segments: base, middle, and top. Only the top and middle segments were crushed for juice analysis; the bottom segment (oldest stem) was discarded. Differences in sugar accumulation are greatest in the young stem (the top segment), but those differences become smaller toward in the older stem (Clements, 1980). Each juice sample was divided into two subsamples: one for Brix-pol analysis (Meade and Chen, 1977) and the other for HPLC analysis (Clarke et al., 1983). The Brix-pol analysis was carried out immediately after the cane sample was crushed. The other set of juice samples was stored immediately at −80°C until the HPLC analysis could be performed. The Brix-pol analysis was used to measure Brix (g kg^{-1}) by electronic refractometry and apparent sucrose (g kg^{-1}) by polarimetry. Apparent purity (%) was computed as follows: (apparent sucrose/Brix) × 100. Sucrose (g kg^{-1}), glucose (g kg^{-1}), and fructose (g kg^{-1}) contents were measured by the HPLC method.

The *t*-test was used to determine whether the sample means between top and middle segments were significantly different (Steel and Torrie, 1980). A combined analysis of variance with two crop cycles of data was performed on each measurement of juice quality to determine the magnitude of genotype × crop interaction effect (SAS, 1988). Plant-cane data on three sugar traits (sucrose, glucose, and fructose) based on the HPLC measurements were used for both principal component and cluster analyses. Cluster analysis was performed on the basis of all three principal components by the average linkage method (SAS, 1988).

RESULTS AND DISCUSSION

The *t*-test comparing the two sample means showed no significant difference between top and middle segments in all four *Saccharum* species and commercial cultivars. Therefore, we used means of top and middle segments for principal component and cluster analyses. The lack of differences between top and middle segments for all sugar traits is likely due to the fact that the stalk samples were taken when cane plants had

Table 1. Analysis of variance of sugarcane juice quality measured by Brix-pol and HPLC methods of the plant-cane and first-ratoon crops from four species and cultivars.

		Mean squares						
		Brix-pol method			HPLC method			
Source	df	Apparent Brix	Apparent sucrose	Apparent purity	Sucrose	Glucose	Fructose	Total sugars†
		g kg^{-1}		%	g kg^{-1}			
Crop cycles	1	52.364	61.952	234.372	36.255	0.015	0.475	50.564
Rep (crop cycles)	2	0.777	0.774	1.608	0.429	0.120	0.062	3.038
Clones	10	41.302**	93.014**	1169.402**	93.226**	0.557**	0.705**	70.762**
Clones × Crop cycles	10	6.380**	6.332**	153.757**	10.383*	0.352**	0.550**	12.895
Error	20	1.464	1.558	35.526	3.253	0.080	0.110	5.692

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
† Total sugars = sucrose + glucose + fructose.

Table 2. Means, ranges, and CV (%) of sugar compositions of four *Saccharum* species plus four commercial cultivars of plant cane.

Measurement†		Commercial cultivar‡	*S. officinarum*	*S. barberi*	*S. robustum*	*S. sinense*
			Brix-pol method			
Apparent Brix, g kg^{-1}	Mean	199.6	196.0	162.2	164.3	188.2
	Range	156.3–231.4	138.0–228.5	110.9–193.5	116.6–214.4	156.5–206.5
	CV %	15.88	11.81	13.73	14.81	6.80
Apparent Sucrose, g kg^{-1}	Mean	175.8	168.3	99.8	103.2	156.7
	Range	128.0–202.6	95.2–203.6	37.9–158.8	45.9–176.1	112.5–183.6
	CV %	19.04	17.24	33.57	31.77	11.86
Apparent purity, %	Mean	87.74	84.14	62.22	60.96	84.34
	Range	81.89–92.22	49.51–92.09	33.23–84.56	27.98–85.98	71.82–89.82
	CV %	4.95	10.48	23.72	22.70	5.30
			HPLC method			
Sucrose, g kg^{-1}	Mean	187.2	139.4	81.0	94.7	127.3
	Range	152.8–205.0	48.8–218.4	48.0–123.8	55.0–163.2	83.0–162.5
	CV %	12.53	33.32	19.96	30.04	20.06
Glucose, g kg^{-1}	Mean	2.0	6.1	10.5	7.5	4.4
	Range	1.8–2.5	1.9–27.0	3.6–22.5	2.5–16.7	2.2–13.2
	CV %	17.72	83.93	50.78	46.82	50.07
Fructose, g kg^{-1}	Mean	2.0	6.3	11.5	7.5	4.6
	Range	1.8–2.5	1.9–26.0	3.5–25.2	2.6–19.0	2.3–9.0
	CV %	16.83	90.16	56.09	49.48	38.45
Total sugar, g kg^{-1}	Mean	191.1	153.4	102.6	109.6	136.3
	Range	156.4–208.7	61.2–227.7	74.2–150.3	61.3–177.4	89.7–175.3
	CV %	12.35	30.79	20.03	27.36	18.92

† All except apparent purity indicate g kg^{-1} by juice sample weight. Apparent purity (%) was computed from (apparent sucrose/Brix) × 100.
‡ Number of clones: Commercial cultivars 4, *S. officinarum* 32, *S. barberi* 30, *S. robustum* 27, and *S. sinense* 28.

reached maturity and after they had been exposed to drought for more than 30 d before sampling (Clements, 1980). Sampling at an earlier time in the season or after rain could affect the relative sugar concentrations for some clones.

A combined analysis of variance with data from both plant-cane and first ratoon crops indicated that the clones did not respond similarly to crop cycles for all traits except total sugar (Table 1). The effect of crop cycles was confounded with the year effect (Kang et al., 1987). The pattern of variation would be expected to change from crop to crop due to a differential response of some clones to crop cycles.

The four commercial cultivars had the highest mean for Brix, sucrose, purity, and total sugar and were the lowest in glucose and fructose (Table 2). *Saccharum barberi* had the lowest means for Brix, sucrose, and total sugar and the highest for glucose and fructose among the five groups of sugarcane clones. *Saccharum officinarum* clones had the second highest sucrose content, and their juice contained a moderately low concentration of glucose and fructose. Brix-pol and HPLC analyses indicated that the concentration of these sugar traits varied within and between species. The variation of these sugar traits was continuous and did not appear to be discrete among species (Fig. 1). *Saccharum officinarum* clones had the widest distribution of sucrose concentration ranging from 48.8 to 218.4 g kg^{-1}, whereas *S. barberi* clones had the narrowest distribution of sucrose concentration ranging from 48.0 to 123.8 g kg^{-1}. The frequency distributions for *S. barberi*, *S. robustum*, and *S. officinarum* were skewed toward high sucrose content, whereas that for *S. sinense* was skewed toward low sucrose content. Combined frequency distributions for the four *Saccharum* species showed a marked skewness toward high glucose or fructose. Both Brix-pol and HPLC analyses showed that a few *S. officinarum* clones exceeded commercial cultivars in sucrose content. These *S. officinarum* clones were originally collected from their natural habitats and from domesticated garden canes, which may have been selected for sweeter chewing canes for many centuries by natives in New Guinea (Artschwager and Brandes, 1958), whereas the commercial cultivars have been intensively selected for high sucrose through breeding. These *S. officinarum* clones, however, may provide useful sugar genes for improving current commercial sugarcane cultivars in the future.

Brix-pol analysis indicated that *S. barberi* and *S. robustum* had the highest coefficient of variation (CV%), whereas *S. sinense* had the lowest coefficient of variation (Table 2). The HPLC analysis, however, indicated *S. officinarum* had the highest variation, whereas the *S. sinense* had the lowest variation in most of the four sugar traits tested, and suggested that *S. officinarum* germplasm could provide sugarcane breeders with a great diversity of genetic resources for these sugar traits.

A simple correlation of sucrose measurements determined by Brix-pol and HPLC analyses was significantly positive, whereas that of Brix-pol sucrose with either glucose or fructose was significantly negative in all five groups of sugarcane (Table 3). Both glucose and fructose showed a negative effect on apparent purity of juice

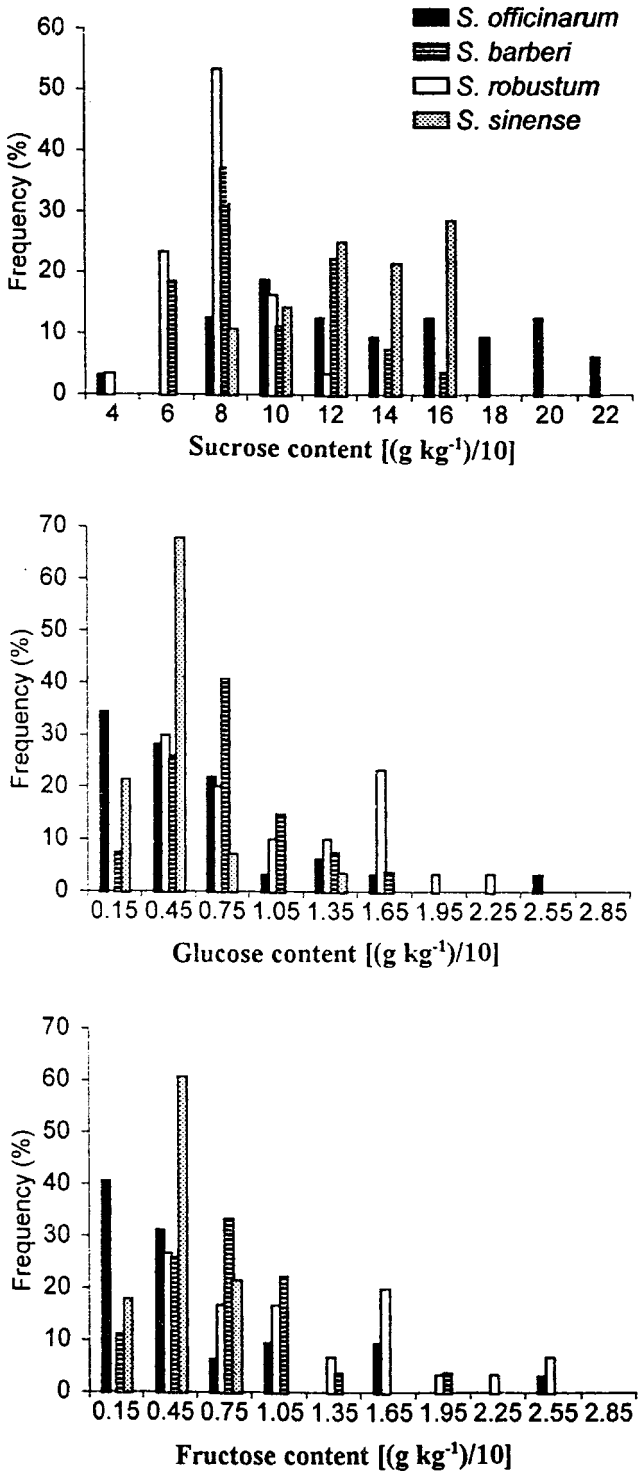

Fig. 1. Frequency distributions of sucrose, glucose, and fructose contents [(g kg^{-1})/10] of four *Saccharum* species determined on the basis of HPLC analysis of the plant-cane crop.

for commercial cultivars, *S. barberi*, *S. robustum*, and *S. sinense*, but the two reducing sugars were not significantly correlated to apparent purity for *S. officinarum*. A significant correlation between sucrose and glucose and between sucrose and fructose (HPLC analysis) was not detected in all four *Saccharum* species, but correlation between glucose and fructose was highly significant.

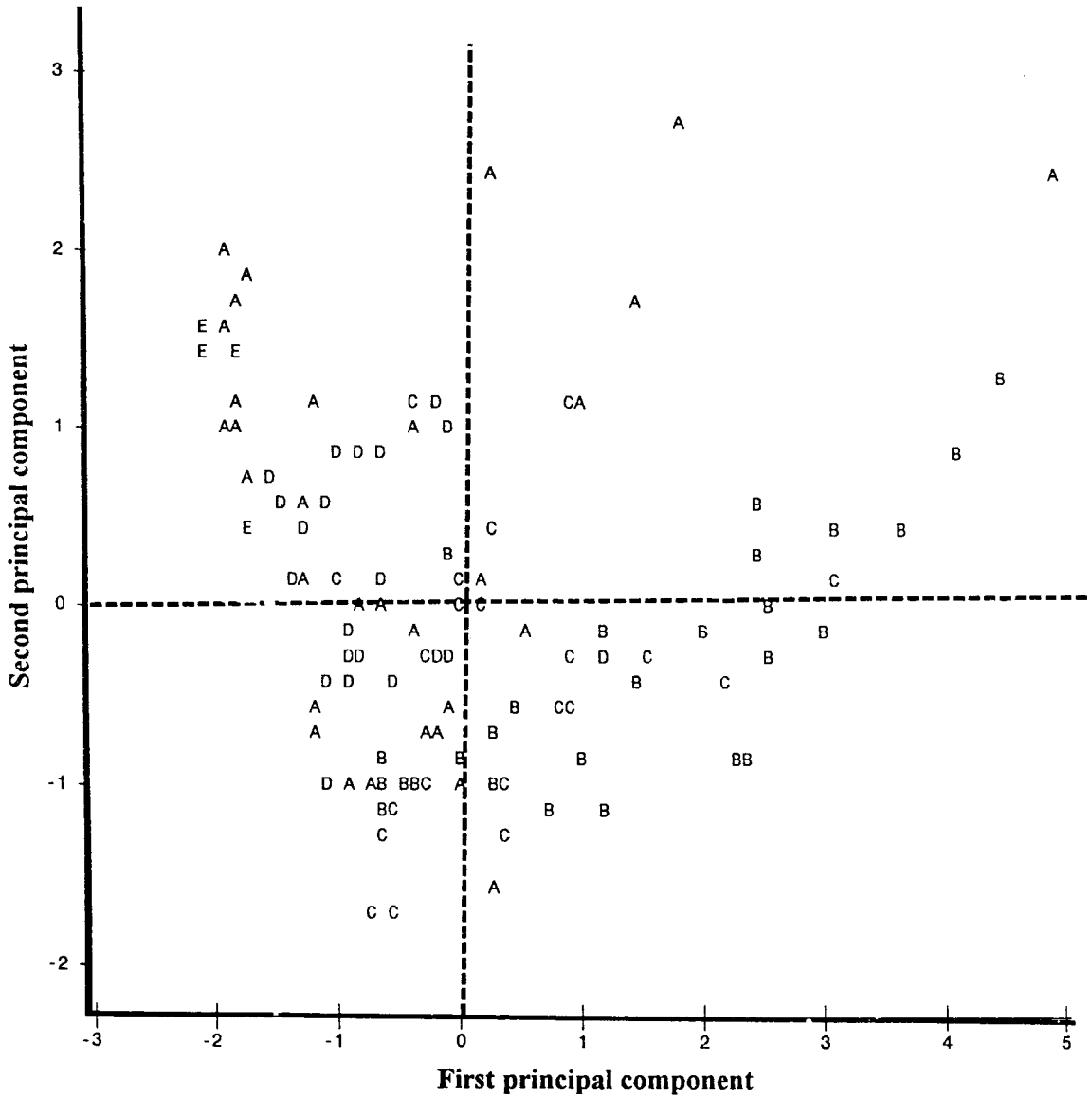

Fig. 2. Plot of the first and second principal components based on the HPLC analysis of sugar composition (sucrose, glucose and fructose) of four *Saccharum* species plus four commercial cultivars of the plant–cane crop. Legends: A = *S. officinarum*; B = *S. barberi*; C = *S. robustum*; D = *S. sinense*; and E = commercial cultivars.

Distribution of the 117 clones of four species and four commercial cultivars on the basis of the first and second principal components based on sucrose, glucose, and fructose contents from the HPLC analysis showed that the first two principal components accounted for 98% of the standardized variation, with the first principal component accounting for 69% of the variation (Fig. 2). The first principal component was a positive measure of both glucose and fructose contents. The second principal component was a large positive measure of sucrose. Three commercial cultivars (CP 70-1133, CP 72-1210, and CP 72-2086) were clustered with a small group of *S. officinarum* in the high sucrose and low glucose–fructose group. *Saccharum officinarum* had the largest dispersion, whereas *S. sinense* had the smallest dispersion. The *S. officinarum* clones were distributed from the lowest glucose–fructose content to the highest glucose–fructose content and from the lowest sucrose content to the highest sucrose content. The *S. sinense* clones were clustered around a long, narrow plot stretching from low sucrose and glucose–fructose contents to moderate sucrose and glucose–fructose contents. Most *S. barberi* clones were distributed around the plot ranging from low sucrose content and low to moderate glucose–fructose content to high glucose–fructose content and moderate sucrose content. Nearly one-half of the clones of four *Saccharum* species were located in a plot, with moderately low sucrose content and moderately low glucose–fructose content overlapping among them. More *S. barberi* clones were overlapped with *S. robustum* than with either *S. officinarum* or *S. sinense*. Three clones, two *S. robustum* (IN 84-50 and IN 84-76) and one *S. officinarum* (NG 96-24), showed an extremely low sucrose content (HPLC sucrose = 55.0 g kg^{-1}, 56.0 g kg^{-1}, and

Table 3. Simple correlations between different sugar traits of the mean measurements of two stalk segments (top and middle) of four *Saccharum* species and one set of commercial cultivars from plant cane.

Correlation	Commercial cultivar†	*S. officinarum*	*S. barberi*	*S. robustum*	*S. sinense*
Apparent sucrose vs. Brix	0.97*	0.98**	0.61**	0.75**	0.84**
Apparent purity vs. Brix	0.75	0.48**	0.38*	0.46*	0.54**
Sucrose (HPLC) vs. Brix	0.92	0.48**	0.41*	0.56**	0.39*
Glucose (HPLC) vs. Brix	−0.94	−0.58**	−0.18	−0.20	−0.53**
Fructose (HPLC) vs. Brix	−0.93	−0.45*	−0.16	−0.26	−0.47**
Apparent purity vs. apparent sucrose	0.89	0.52**	0.94**	0.89**	0.72**
Sucrose (HPLC) vs. apparent sucrose	0.98*	0.51**	0.61**	0.68**	0.45*
Glucose (HPLC) vs. apparent sucrose	−0.98*	−0.59**	−0.66**	−0.40*	−0.59**
Fructose (HPLC) vs. apparent sucrose	−0.99**	−0.44*	−0.65**	−0.43*	−0.57**
Sucrose (HPLC) vs. apparent purity	0.95*	0.35	0.50**	0.64*	0.52**
Glucose (HPLC) vs. apparent purity	−0.92	−0.33	−0.75**	−0.45*	−0.68**
Fructose (HPLC) vs. apparent purity	−0.91	−0.24	−0.77**	−0.46*	−0.61**
Glucose vs. sucrose (HPLC)	−0.99**	0.02	0.04	0.09	−0.29
Fructose vs. sucrose (HPLC)	−0.99**	0.02	0.02	0.07	0.22
Fructose vs. glucose (HPLC)	0.99**	0.86**	0.95**	0.97**	0.84*
n	4	32	30	27	28

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
† Degrees of freedom: Commercial cultivars = 2; *S. officinarum* = 30; *S. barberi* = 28; *S. robustum* = 25; and *S. sinense* = 26.

Table 4. Clones in 11 clusters of four *Saccharum* species plus four commercial cultivars based on the cluster analysis from plant cane.

Cluster		Commercial cultivar	*S. officinarum*	*S. barberi*	*S. robustum*	*S. sinense*
I	(33)†		Uahi A Pele 50; NG 77-142; IS 76-418; Saipan; Mahona; NG 28-287; NG 77-135; IN 84-31; Malabar; D1135	Rhea Sport; Manga Sic; Dark Pindaria; Kalari; Ketari; Rhea; Chin; Maneira Coimbatore	IN 84-76; IN 84-50; NG 57-54; NG 77-235; IJ 76-339; US 57-141-5; US 57-159-13; IM 76-253; Molokai 5573	Kacai; Merthi Zell; Kavangire; Pansahi 204; Ketari II; Ar Chi
II	(38)	POJ 2725	NG 57-257; Old Jamaica; NG 28-4; *S. officinarum* #7; Akoki #22; Striped Tanna; Kerah; Henah	Hemja	US 57-254-7; IM 76-232; NG 77-21; IJ 76-501; NG 77-83; NG 77-159; NG 77-107	Agaul; McIlfrum; Berlin; Uba del Nataal; Tekcha; Sinense; Chuk Che; Tukuyu Dist. #1; Tekcha Chung Tseng; Merthi; China; Japonesa; Uba Naquin; Oshima; Cayana 10; Khakai; Uba India; Tekcha Chiki Island; Tekcha Okinawa; Zwinga; Maneira
III	(19)		NG 77-13; NG 96-24	Dhaulu; Khagzi; Nargori; Newra; Semari; Sararoo; Mantna; Hatooni; Ganapathy	NG 77-84; NG 28-289; IN 84-45; NH 70-15; NG 57-249; NG 77-94; NG 57-55; NG 77-55	
IV	(2)			Baroukha		Uba Striped
V	(10)	CP 70-1133 CP 72-1210 CP 72-2086	NG 28-33; Green German; Sylva; Spaansch; NG 77-81; NG 28-55; White Transparent			
VI	(3)		UM 68-10; NG 57-59		NG 28-218	
VII	(1)		NG 51-42			
VIII	(1)		NG 77-92			
IX	(11)			Sunnabile; Tereru; Sarauti; Ruckri; Mathna Shaj; Mungo; Mesangen; Rounda; Agoule	NG 77-147; IJ 76-534	
X	(2)			Paunra; Rakhra		
XI	(1)		Muntok Java			

† Number of clones per cluster are in the parentheses.

48.8 g kg^{-1}, respectively). All clones with high sucrose content (190 g kg^{-1} or higher) belonged to *S. officinarum* (Spaansch, NG 57-59, NG 77-81, White Transparent, NG 51-42, and NG 77-92) and commercial cultivars (CP 70-1133, CP 72-1210, and CP 72-2086), which also were low in glucose and fructose content. One *S. officinarum* clone, Muntok Java, and two *S. barberi* clones, Rakhra and Paunra, had moderate sucrose contents (142.7 g kg^{-1}, 102.6 g kg^{-1}, and 89.9 g kg^{-1}, respectively) and high glucose and fructose contents (glucose = 27 g kg^{-1}, 22.5 g kg^{-1}, and 19.9 g kg^{-1}, respectively; and fructose = 26 g kg^{-1}, 25.2 g kg^{-1}, and 24.5 g kg^{-1}, respectively). No clear-cut separation occurred among the four species, but they showed a pattern of variation. It was possible to identify a sugar trend on the plot of the first and second principal components.

Cluster analysis using the principal components based on sucrose, glucose, and fructose contents from the HPLC measurement, four species and four commercial cultivars were grouped into 11 clusters (Table 4). Among the four *Saccharum* species, *S. officinarum* clones were divided into the largest number of groups (nine clusters) and diversity, whereas *S. sinense* was divided into the fewest (three clusters). These clusters overlapped among species and were highly unbalanced with respect to number of clones. Three commercial cultivars (CP 70-1133, CP 72-1210, and CP 72-2086) and seven clones of *S. officinarum* (NG 29-33, Green German, Sylva, Spaansch, NG 77-81, NG 28-55, and White Transparent) shared Cluster V in which the clones had high sucrose content and low glucose and fructose content (mean sugar contents: sucrose 196.6 g kg^{-1}, glucose 2.4 g kg^{-1}, and fructose 2.4

Table 5. Means of sugar measurements using Brix-pol and HPLC analyses for 11 clusters of four *Saccharum* species plus four commercial cultivars from plant cane.

Cluster	No. of clones	Brix-pol method			HPLC method			
		Brix	Sucrose	Purity	Sucrose	Glucose	Fructose	Total sugar†
		g kg^{-1}		%	g kg^{-1}			
I	33	179.3	138.7	763.1	87.5	4.3	4.3	99.5
II	38	188.9	156.9	83.69	137.5	4.8	4.9	147.0
III	19	154.8	93.7	61.82	79.1	9.0	8.9	97.1
IV	2	166.3	103.8	67.24	84.5	14.5	9.6	108.6
V	10	217.0	194.6	861.2	196.9	2.5	2.4	201.8
VI	3	179.9	146.2	82.78	149.7	12.4	12.4	174.5
VII	1	194.0	16.69	85.86	206.2	10.6	10.9	227.7
VIII	1	149.6	157.4	79.03	197.1	15.7	17.6	188.2
IX	11	149.6	65.8	45.52	75.3	15.1	17.4	106.0
X	2	167.6	83.6	49.72	96.3	21.4	24.9	142.3
XI	1	150.0	111.6	74.18	142.7	27.0	26.0	198.5
Overall mean	121	178.9	134.4	73.70	113.7	7.0	7.3	128.3

† Total sugar = sucrose + glucose + fructose.

g kg^{-1}). Three *S. officinarum* clones, NG 51-42 (Cluster VII), NG 77-72 (Cluster VIII), and Muntok Java (Cluster XI), were each classified into a separate cluster with a single clone. One *S. robustum* clone (NG 28-218) and two *S. officinarum* clones (UM 68-10 and NG 57-59) were grouped together (Cluster VI) with a moderately high mean value for sucrose (184.5 g kg^{-1}) and moderately high glucose (12.6 g kg^{-1}) and fructose (13.2 g kg^{-1}) concentrations. Cluster analysis did not reflect the traditional classification of these four *Saccharum* species and the grouping appeared to be relatively ambiguous. The clustering was not clear cut. The ambiguous grouping could be due to the sugar data being continuous. There is a possibility that some of the accessions used in this study could be incorrectly classified by the sugarcane collectors or curators. For any one individual clone, the sugar measurements were a function of its environment and of its particular genetic individuality such as the interaction of clone and crop cycle (Table 1).

The characteristics of these 11 clusters, as shown by means of three sugar components, indicated that Cluster V had the highest content of sucrose and total sugar, but the lowest glucose and fructose content (Table 5). Clusters I, II, and III had very low contents of both glucose and fructose with a moderate sucrose content, whereas Clusters X and XI had a very high content of both glucose and fructose and with a moderate sucrose content. Clusters VII and VIII had a very high sucrose content and a moderate glucose and fructose content. Clusters VII, VIII, and XI contained only one clone each of *S. officinarum* and showed unique sugar compositions: Cluster VII (NG 51-42) had a high sucrose content and moderate glucose and fructose contents; Cluster VIII (NG 77-92) had a high sucrose content and moderately high glucose and fructose contents; and Cluster XI (Muntok Java) had high glucose and fructose contents and a moderately high sucrose content. The means of the three sugar measurements of Cluster II were close to the overall means. The clustering analysis revealed an intergradation of sugar characters among the *Saccharum* species.

The variation of sugar composition within the four *Saccharum* species appears to be continuous. Principal component and cluster analyses did not produce clear-cut separations between the four species of *Saccharum*. The grouping, however, revealed a pattern of variation of the sugar traits. Information on the sugar composition of these species could help curators characterize clones in the World Collection. This information should also assist sugarcane breeders in selecting desired clones for their breeding programs.

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